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Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data

D.P. Roy[a,*], Y. Jin[b], P.E. Lewis[c], C.O. Justice[b]

[a]Department of Geography, 1113 LeFrak Hall, University of Maryland, College Park, MD 20742 and NASA Goddard Space Flight Center, Code 614.5, USA
[b]Department of Geography, 1113 LeFrak Hall, University of Maryland, College Park, MD 20742, USA
[c]Remote Sensing Unit and NERC Centre for Terrestrial Carbon Dynamics, Department of Geography, University College London, 26 Bedford Way, London, WC1H 0AP, UK

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Abstract

The remote sensing of Earth surface changes is an active research field aimed at the development of methods and data products needed by scientists, resource managers, and policymakers. Fire is a major cause of surface change and occurs in most vegetation zones across the world. The identification and delineation of fire-affected areas, also known as burned areas or fire scars, may be considered a change detection problem. Remote sensing algorithms developed to map fire-affected areas are difficult to implement reliably over large areas because of variations in both the surface state and those imposed by the sensing system. The availability of robustly calibrated, atmospherically corrected, cloud-screened, geolocated data provided by the latest generation of moderate resolution remote sensing systems allows for major advances in satellite mapping of fire-affected area. This paper describes an algorithm developed to map fire-affected areas at a global scale using Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance time series data. The algorithm is developed from the recently published Bi-Directional Reflectance Model-Based Expectation change detection approach and maps at 500 m the location and approximate day of burning. Improvements made to the algorithm for systematic global implementation are presented and the algorithm performance is demonstrated for southern African, Australian, South American, and Boreal fire regimes. The algorithm does not use training data but rather applies a wavelength independent threshold and spectral constraints defined by the noise characteristics of the reflectance data and knowledge of the spectral behavior of burned vegetation and spectrally confusing changes that are not associated with burning. Temporal constraints are applied capitalizing on the spectral persistence of fire-affected areas. Differences between mapped fire-affected areas and cumulative MODIS active fire detections are illustrated and discussed for each fire regime. The results reveal a coherent spatio-temporal mapping of fire-affected area and indicate that the algorithm shows potential for global application.

Keywords: Fire; Fire-affected area; Burned area; Change detection; BRDF; MODIS; Time series

1. Introduction

Fire is a prominent disturbance factor and is an agent of environmental change with local to regional impacts on land use, productivity, carrying capacity, and biodiversity, and regional to global impacts on hydrologic, biogeochemical, and atmospheric processes (Csiszar et al., 2004). Fire plays a role in a number of land surface atmosphere interactions and is a significant source of trace gases and aerosols impacting atmospheric chemistry and the radiation budget (Crutzen & Andreae, 1990; French et al., 2003; Govaerts et al., 2002; Scholes & Andreae, 2000; van der Werf et al., 2003). Fire is an important ecosystem process effecting vegetation structure and composition (Johnson & Miyanishi, 1997) and in many land use systems is a proximate cause or indicator of land cover change (Bucini & Lambin, 2002; Cochrane, 2003; Janetos & Justice, 2000). The frequency, intensity, season, and type of fire that prevails in an area are collectively referred to as the fire regime. It remains unclear if fire regimes will change as human population, their land use practices, and the climate change (Stocks, 1998; Murphy et al., 1999; UNEP, 2002). Certainly, there is a perceived increasing incidence, extent, and severity of uncontrolled burning globally that has lead to calls for international environmental policy concerning fire (Stocks et al., 2001). Such concerns strengthen the need to provide reliable fire information to policymakers, scientists, and resource managers. The satellite derived information, includes the location, timing, instantaneous radiative power, temperature and size of active fires, and the spatial extent of burning. In this paper, we use the term “fire-affected area” to denote the area subjected to fire. This is in recognition that fire often does not burn the entire surface it passes over and because more pejorative terms, such as “fire scar” or “burn scar”, do not reflect the beneficial ecological effects of fire in many parts of the world.

* Corresponding author.
E-mail address: droy@kratmos.gsfc.nasa.gov (D.P. Roy).

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Satellite remote sensing provides the only means of monitoring vegetation burning at regional to global scale. The Vegetation Fire Information System proposed at the Dahlem Conference on Fire in the Environment in 1992 provided a vision for an information system composed of satellite and in-situ observations to serve the global change community (Crutzen & Goldammer, 1993). Subsequently, remote sensing requirements for measuring the timing and spatial extent of fires globally have been included in summary documents generated by the Committee on Earth Observation Satellites (CEOS) and the Global Climate Observing System (GCOS) (CEOS, 2000; GCOS, 1997). Satellite data have been used to monitor fire globally for more than two decades using active fire detection algorithms developed for different sensors to take advantage of the elevated radiance signal of hot fires (Arino & Rosaz, 1999; Dozier, 1981; Elvidge et al., 2001; Giglio et al., 2003; Matson & Dozier, 1981; Prins & Menzel, 1992). It is well established that for most fire regimes satellite active fire detections do not reliably define the fire-affected area. This is because the satellite may not overpass sufficiently frequently to capture the spatial details of how fires propagate across landscapes, and because clouds and optically thick smoke may preclude active fire detection (Justice et al., 2002b; Robinson, 1991). Recognizing these limitations, methods to map fire-affected area have been developed in the last decade using moderate and coarse spatial resolution satellite data (e.g., Barbosa et al., 1999; Eva & Lambin, 1998a; Fredericksen et al., 1990; Fraser et al., 2000; Kasischke & French, 1995; Roy et al., 2002b; Simon et al., 2004; Tansey et al., 2004; Zhang et al., 2003). Most approaches capitalize on the spectral impact of fire effects (associated with deposition of charcoal and ash, removal of vegetation, and alteration of the vegetation structure) and use multi-temporal satellite data, which provide several advantages over single date data for mapping fire-affected areas (Eva & Lambin, 1998b; Pereira et al., 1997). Despite the range of studies undertaken, there is no consensus algorithm and no global algorithm has yet been implemented on more than 1 year of remotely sensed data (Simon et al., 2004; Grégoire et al., 2003). Comparison of fire-affected area products generated recently using contemporaneous time series data sensed by the Moderate Resolution Imaging Spectroradiometer (MODIS) (Roy, 2003), the Systeme Pour l'Observation de la Terre (SPOT-VEGETATION) (Tansey et al., 2004), and the Along Track Scanning Radiometer (ATSR-2) (Simon et al., 2004) for southern Africa indicate substantive differences and highlight the need for rigorous product validation (Korontzi et al., 2004).

The availability of robustly calibrated, atmospherically corrected, cloud-screened, geolocated data provided by the latest generation of moderate resolution remote sensing systems allows for major advances in satellite mapping of fire-affected area. Arguably, these data allow for the development of more physically based algorithms that are less dependent upon imprecise but noise tolerant classification techniques. As part of NASA's Earth Observing System (EOS), the Moderate Resolution Imaging Spectroradiometer (MODIS) is onboard the Terra (launched 1999) and Aqua (launched 2001) polar orbiting satellites and their data are being used to generate global coverage data products on a systematic basis (Justice et al., 2002a). The algorithm used to define the MODIS active fire product has been refined several times (Giglio et al., 2003; Justice et al., 2002a; Kaufman et al., 1998). A complementary MODIS algorithm defined to map fire-affected area has been developed and demonstrated in southern Africa (Roy, 2003; Roy et al., 2002b). The algorithm uses a bi-directional reflectance model-based change detection approach to map the 500 m location and approximate day of burning. It detects the approximate date of burning by locating the occurrence of rapid changes in daily MODIS reflectance time series. The algorithm maps the spatial extent of recent fires and not of fires that occurred in previous seasons or years. The algorithm is an improvement on previous methods due to the use of a bi-directional reflectance model to deal with angular variations found in satellite data and the use of a statistical measure to detect change probability from a previously observed state. The algorithm does not use training data and is adaptive to the number, viewing, and illumination geometry of the data, and to the amount of noise in the data. This paper describes refinements and improvements made to the algorithm for its systematic global application and illustrates its functioning for southern African, Australian, South American, and Boreal fire regimes. The improved algorithm will be implemented in the MODIS land production system in an attempt to systematically map fire-affected areas globally for the 6+-year MODIS observation record.

11. Conclusions

We have described in detail an improved algorithm developed for systematic global mapping of fire-affected areas using MODIS 500 m land surface reflectance time series data. It is based on a bi-directional reflectance model-based expectation change detection approach that does not require training data or other sources of information, including human intervention. We have improved on the original algorithm (Roy et al., 2002b) by making the new global algorithm (i) operate on multiple wavebands, (ii) better differentiate between fires and other types of change, (iii) use more robust temporal constraints, (iv) reduce sensitivity to non-random underlying changes and gaps and unmodeled noisy observations, and (v) use spatial contextual information to capture the increased likelihood of fire occurrence near confidently detected fire-affected areas. These improvements serve to derive more robust measures and to better propose the underlying cause of any detected change. The algorithm is potentially applicable to the mapping of other land-cover conversion or modification processes that are characterized by rapid reflectance change.